# A Review on Spectrum Mobility for Cognitive Radio Networks

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**Abstract:** ***Cognitive radio is one of the technologies which has the potential to improve the spectrum utilization and network performance. Spectrum Mobility is an indispensable component in cognitive radio network that not only guarantees desired QoS of primary users but also grants resilient service for secondary users. Spectrum Mobility occurs when the primary user appears in the licensed band occupied by secondary user and it is used to avoid interference between primary and secondary users. This paper provides a systematic current overview of spectrum mobility process, various performance metrics and challenges regarding spectrum mobility are pointed out and finally a number of promising concepts and schemes are briefly presented.***

**Keywords:** Cognitive radio, spectrum holes, spectrum handoff, handoff delay**.**

## 1. Introduction

With the dramatic growth of high data rate communications in both licensed and unlicensed spectra, there is an urgent need to satisfy the explosive demand for radio spectrum. But as per FCC frequency chart, there are no available segments of unused spectrum to help carriers to meet their ever increasing needs. At the same time actual measurements reveal that most part of radio spectrum is underutilized. In many bands spectrum access is more significant problem as compared to scarcity of spectrum [1]. Thus there is discrepancy between spectrum allocation and today's lack of spectrum and these all motivates to expand the availability of spectrum with smarter technology. The key to resolve this well known dilemma between spectrum scarcity and underutilization lies in the concept of Dynamic spectrum access and the emerging technology is cognitive radio [1].Being dynamic means that the transmission parameters like bandwidth, transmitter power, center frequency etc. may vary with time. Cognitive radio is a promising technology that can enhance the radio spectrum utilization to cope up with spectrum hunger situation, increase the network capacity and can push the research towards new means of exploiting wireless media by applying intelligence in existing traditional wireless communication.

### 1.1 Cognitive Radio

Cognitive radio is the radio revolution at present. This technology offers a high degree of flexibility and transforms radio node from blind executors of predefined set of rules to a system that is aware of its surroundings [2] such that it can exploit the spectrum in an opportunistic manner, with two primary objectives: first is highly reliable communications whenever and wherever required and other one is efficient utilization of radio spectrum [1]. In the face of seemingly under utilization of spectrum, cognitive radio technology rushed into service with the goal to develop a radio that is able to sense the surrounding environment, detect the presence or absence of legacy users or spectrum holes [1] or white spaces and can change or can adapt its transmitter parameters based on interaction with environment in which it operates.

### 1.2 Cognitive Radio Network

The components in cognitive radio network can be classified as primary network and cognitive radio network. The primary network or licensed network has a license to operate in certain band. The cognitive radio network or dynamic access network are capable of accessing both licensed and unlicensed slices of spectrum through wideband sensing capability. It includes secondary users or unlicensed low priority users as compare to primary users and there is no negotiation between primary and secondary network or simply primary system is unaware of secondary system.

### 1.3 Spectrum Management Framework

The cognitive radio networks will have to respect the policies, defined by regulatory bodies which are based on central idea that cognitive radio can access and share the spectrum in an opportunistic manner with licensed users, provided that there should have no or very limited impact on licensed user communication [3]. Such a solution can be complicated and impose unique challenges due to their coexistence with primary networks, typical dynamic behavior of primary user, interference avoidance and QoS awareness. In In order to meet these challenges, cognitive radio operates on cognitive cycle which comprises of 4 main steps. These steps are: spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility [4].

- Spectrum sensing: It is the fundamental requirement of cognitive system to work. A cognitive user should monitor the spectrum bands to determine the presence or absence of primary user before transmission. Spectrum sensing is done in order to minimize the impact of secondary users on primary users. Basically spectrum sensing techniques are classified into three main groups: Primary transmitter detection which includes matched filter detection, energy detection and feature detection. The other two groups include primary receiver detection and interference temperature management.
- Spectrum decision: Based on information of spectrum sensing, a spectrum band is analyzed and best available spectrum is selected for transmission. This allocation is focused mainly on spectrum availability, cost of

communication and quality of service requirements.

- Spectrum sharing: Cognitive radio has to access and share the spectrum with multiple other secondary or cognitive users. Spectrum sharing is to distribute the spectrum among all cognitive and non-cognitive users such that there should be no collisions among them.
- Spectrum Mobility: The fourth step in spectrum management and one of the most prominent features of cognitive radio networks will be the ability to switch to different portions of radio spectrum as soon as spectrum left over or spectrum holes are detected. Spectrum mobility is the technique that will enable cognitive radio networks to achieve this goal. As licensed users or primary users have the right to their spectrum slice thus cannot accept any interference thus in this direction the most important and challenging issue of spectrum mobility is to avoid interference to primary users and attain a seamless communication. Spectrum mobility will be further explored in sec 2.

This paper presents a short overview of cognitive radio systems. More specifically, the main focus of discussion in this paper is on spectrum mobility or handoff which is crucial and challenging part of cognitive radio networks. Various handoff algorithms are described. This paper will explore the issue of handoff delay caused by spectrum mobility process and how it depends on the handoff schemes involved in handoff process.

## 2. Spectrum Mobility in Cognitive Radio Network

Spectrum mobility enables the secondary users to switch to idle channels. Spectrum mobility occurs when the primary user occurs in the band occupied by secondary user. Since these secondary users has no control over the resource availability, thus secondary system must be designed to sense leftover spectrum as quickly as possible and switch to next idle slice of spectrum as soon as the primary user appears [5]. The most important and challenging issues in spectrum mobility is the coexistence of secondary users with primary ones, to avoid interference to primary users without any negotiation with primary network and attain a seamless communication. In order to address the problem of interference, interference management is done at both transmitter and receiver. At receiver, interference limit or interference temperature is calculated on the basis of location, fading, modulation, coding and accordingly the power of transmitter are restricted. On the other hand, at transmitter, by using sensing procedures, first of all it classifies the status of channel and then determine when, where and with how much power is used for transmission. Power control in cognitive radio mitigates unnecessary interference. Further discussion of interference management is omitted here to reduce the complexity, as spectrum handoff is the area of discussion.

### 2.1 System Model

- Centralized vs. decentralized secondary network: In centralized approach, there is a fusion center or base station which manages the communication and decision making. It ensures no collision between the secondary connections while in decentralized case which is based on locally observable channel conditions, there is no fusion center, all secondary users communicate among them and a distributive algorithm is carried out repeatedly until all secondary users converge to a decision.If the central entity controls the handoff process,then it is called centralized otherwise it is decentralized. In the work [6], Zhang considered two scenarios: opportunistic and negotiated conditions. In the first opportunistic scenario, there is no central entity whereas in later case a central entity is there to command and control the spectrum.
- Spectrum handoff modeling: Generally the schemes proposed for spectrum handoff modeling in cognitive radio networks can be categorized into two main groups: slot based and connection based [7]. In the former approach, each slot consists of sensing phase and transmission phase and spectrum handoff can be performed at each time slot while in the later case, handoff can be performed only on the occurrence of primary user. Here the transmission of each secondary connection is back to back; continuous in manner until the appearance of secondary user [8]. M/G/1 Queuing Model (connection-based) have been studied and used in literature by some researchers in [5], [7], [10] in which primary users are inserted into high priority queue while secondary users are placed into low priority queue.Comparison of various channel usage models on the basis of type of modeling technique is given in [7].

### 2.2 Spectrum Mobility process

Spectrum Mobility or handoff process is carried out when channel occupied by secondary users is interrupted or reclaimed by the occurrence of primary users. As soon as the primary user appears, secondary user has to vacate the frequency channel to avoid interference to primary user and switch to other available free channel to resume and finish its ongoing transmission. Figure1. indicates an example with steps that are included in handoff process. Here multiple spectrum handoffs occur during packet transmission. In this figure PU stands for primary user similarly SU stands for secondary user. Handoff delay, one of the performances metric is also indicated below in the figure.

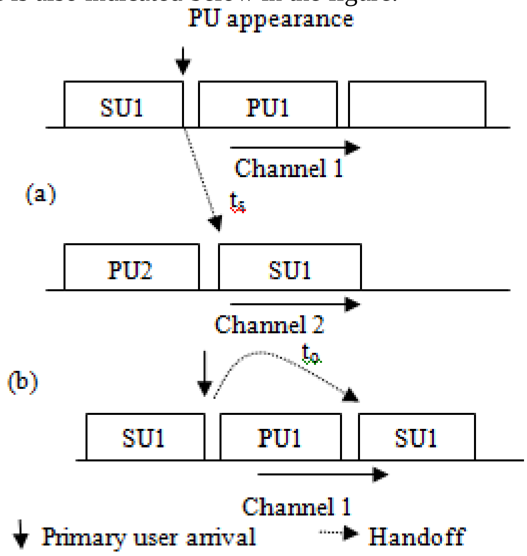


**Figure 1:** An example of channel selection in spectrum mobility

- Firstly, let the secondary user selects channel 1 and start transmits its packets. Solid arrow shows interruption due to appearance or arrival of PU on channel 1.
- When a SU is interrupted by PU, there are two possible cases. In the first case (a), when the SU is interrupted by PU, it pause its transmission, change its operating channel to other channel, like channel 2 and resume its transmission. A delay here arises because of switching, and it is referred as handoff delay (denoted by $t_s$).
- However, at second interruption in channel 2, in other case (b) , SU stays on current channel 2.It needs to wait until high priority PU of channel 2 finish its transmission; here handoff delay is the busy period that is taken by PU to finish its transmission, denoted by $t_o$.
- A similar procedure will be repeated if SU is interrupted by PU appearance on the selected channel. Note that the appearance of PU is stochastic in nature; it adds more complexity to handoff process and is difficult to achieve fast and smooth spectrum transition limited to performance degradation of secondary users during handoff . Thus the process of spectrum handoff can be realized in two phases:
- Monitoring or detection of primary users.
- Link maintenance.

Secondary user must be able to pause its transmission, vacate the channel, on detecting primary user occurrence. Furthermore, secondary user needs to perform link maintenance to reconstruct the communication [6]. In a nutshell, while performing spectrum handoff the secondary user has to suspend its transmission and resume its unfinished data transmission again on finding a suitable target channel.

## 3. Performance Metrics

Factors which determine the performance for spectrum handoff are

- Link Maintenance Probability: It is defined in [6] as the probability that link is successfully maintained when secondary user vacates the channel.
- Handoff delay: It is referred as the duration from the instant of pausing transmission until the instant of resuming the transmission [10]. For real time multimedia services, handoff delay is very significant.
- Number of handoff trials: The number of handoff trials during entire transmission duration is another important performance measure. As spectrum handoff trials increases, the probability of secondary user to maintain an established link increases but it also increases the transmission time [10].It can also be taken as channel switching rate, every time the channel switches, it includes some sort of delay and it decreases the capacity of network.
- Non-completion probability: It is the probability that secondary users cannot complete its transmission [6].
- Extended data delivery time: In the study [7] Wang et al introduced extended data delivery time of secondary connection as a new performance metric. As the secondary connection is interrupted a number of times by the primary users thus the extended data delivery time include the time duration from the instant of starting transmitting data until the instant of finishing the whole connection including all these interruptions.

## 4. Spectrum Mobility Algorithms

**Non spectrum / predetermined spectrum / radio sensing based spectrum handoffs**.

Wang et al. [9] consider three types of spectrum handoff: Non spectrum handoff, the pre-determined channel list spectrum handoff, and the spectrum handoff based on radio sensing scheme. In the first non spectrum handoff scenario cognitive radio users wait until the primary user finish their transmission to send again over the same channel. In the second predetermined channel list scenario, secondary users prepares a candidate channel list for handoff. As soon as the primary user reclaims the occupied channel by secondary user, the transmission for secondary user will be switched to first channel in predetermined list. Another spectrum handoff scheme based on sensing is to determine the target channel. Here in this case a target channel for spectrum handoff is selected based on wide band radio sensing performed by cognitive radio users. An analytical model is of great importance for performance analysis thus has been introduced in the context to investigate the performances of three considered scenarios on the basis of effective data rate and link maintenance probability. Here the system model belongs to slot-based modeling technique. Simulation result shows that sensing based spectrum handoff surpasses the predetermined channel list handoff in terms of successful channel selection for spectrum handoff. The effective data rate of secondary user in predetermined channel list and radio sensing method is higher than the non spectrum handoff.

### 4.1 Reactive and proactive sensing spectrum handoff

Spectrum handoff is mainly focused on the selection of appropriate channel. According to target channel decision method, Wang et al. in [5], [10] generally categorizes the spectrum handoff mechanism into reactive sensing spectrum handoff and proactive sensing spectrum handoff. In reactive sensing spectrum handoff, the secondary user perform searching and spectrum switching after detecting a primary user while proactive spectrum handoff is proposed to let unlicensed users evacuate the channel before primary user utilizes it to avoid unwanted collisions according to long term observation results. Moreover, the author compared these two major handoff schemes on the basis of transmission delay [10].

### 4.2 Partially observable Markov decision process based spectrum handoff (POSH)

Ma et al. [11] categorizes the target channel selection schemes into pre-sensing and post-sensing on the basis of sensing. As channel and behavior of primary user is dynamic in nature, post-sensing approaches are suggested to have more accuracy as compared to pre-sensing schemes. Nevertheless, in spite of its simplicity, post sensing is not perfect solution as these approaches results in long sensing times and thus could decrease the performance. A partially observable Markov Decision process (POSH) is exploited to find the optimum sensing time to reach the maximum throughput. This is done by partially sensing the available frequency channels at the time of spectrum handoff. Simulation results show that number of waiting time slots acquired by POSH algorithm dropped significantly as compared to random channel selection and no spectrum handoff scheme in both better and worse channel conditions.

### 4.3 Common hopping based proactive handoff

To address the sensing delay and to avoid collisions to primary users Song and Xie in [12], proposed a proactive spectrum handoff in ad hoc network. Furthermore, a more realistic common hopping as network coordination scheme is considered and investigated rather than common control channel. On contrary to previous work, multiple secondary users are considered. A default hopping pattern is acquired and all the secondary user devices follow this pattern. When communication is established among two secondary users, handshake signals are exchanged across those communicators; channel hopping is interrupted in the meantime and is resumed as soon as the transmission is over. Furthermore, distributed channel selection algorithm is added to hopping to mitigate the secondary user collisions and handoff delay. When the secondary user is passive, it broadcasts the channel availability information to surrounding secondary user nodes. Simulation results show the effectiveness of algorithm in multiuser environment, proposed algorithm performs better in terms of higher throughput.

### 4.4 Spectrum handoff in opportunistic and negotiated conditions

In the study [6], Zhang consider that in opportunistic situation, on the arrival of primary user, the secondary user may desert the channel to primary user unlike in negotiated situations where primary user is allocated on a channel that is not occupied by secondary user. If all the channels are busy on the arrival of primary user then the secondary user has to evacuate the channel to the primary user under the control of central entity or base station. The comparison between these two scenarios reveal that opportunistic spectrum handoff outperforms the negotiated one as it is more effective and is able to achieve higher secondary user service completion but needs more handoff trials

### 4.5 Spectrum handoff using Backup channel solution

In order to cope up with delay sensitive applications and error of prediction, Lertsinsrubtavee et al. in [13] proposes a backup channel solution. Here the secondary users can hold a supplementary channel for a limited time which can assist in seamless communication promptly. Furthermore, two possibilities are considered. One is full backup solution and the other one is short time backup solution. In the first scenario, secondary user reserves at least one backup channel all the time however it reduces the spectrum utilization. To address this problem, other scenario is considered, where the backup channel is kept for a short duration of time.

### 4.6 Greedy target channel selection

As the transmission delay is one of the important performances metric in cognitive radio mobility, two strategies are proposed, one is always stay strategy and other one is always changing strategy. Further numerical results are drawn in (1), (2), (3), and (4) [10] and on the basis of that greedy selection approach is proposed. Greedy selection wisely selects the target channel with minimum transmission delay. In this strategy, secondary user prefers stay strategy or always changing strategy on the basis of occurrence rate of primary users. If the rate of occurrence is lower, the secondary users prefer always changing strategy otherwise it will be turned on to stay strategy on interruption by primary users. Moreover, the author proposed a pre-emptive resume priority (PRP) M/G/1 model to distinguish the spectrum usage behaviors between primary and secondary users in cognitive radio networks [10].

### 4.7 Classification based prediction method

In the study [14], Hoyhtya et al. introduced the idea of "classification based prediction" which is a learning method to observe the traffic pattern and then forecast the passive period of a channel. Traffic is classified as deterministic one and stochastic one on the basis of periodicity. The proposed method figures out the traffic type of each channel and then further makes a choice of prediction method based on that. The cognitive radio device aggregates the information of spectrum usage by means of sensing of spectrum; moreover a database is created and updated where this information is stored to define the present status of each channel. Further this information is utilized to choose predictive, random or optimal channel switching schemes for spectrum handoff process. Simulation results shows that the sensing time has a great impact on the performance as compare to switching time. Higher gain can be attained with the classification based prediction method besides this it helps in reducing the collisions of secondary users with primary ones.

### 4.8 Spectrum handoff using guard channel

Aman et al. [15], [16] describes the concept of using guard band channel in spectrum handoff to mollify the handoff delay and decrease the blocking probability of secondary users. A significant improvement in delay values is shown in simulation results when compared with random selection approach [16].

### A proactive spectrum handoff without common control, single and multiple rendezvous coordination schemes

Extending the work in [12], Song and Xie [17] introduced coordination between secondary users without widely accepted common control channel. Nevertheless, in spite of simplicity of global control channel, yet it is difficult to locate this channel throughout the network and it can be influenced by primary user appearance on control channel. Single rendezvous coordination scheme for one pair and multiple rendezvous coordination scheme for multiple pair of secondary users is proposed based on common hopping concept. In single rendezvous coordination scheme, only one pair of secondary users can set up a link and exchange information at a time while in later case multiple pairs can take part in this activity and a time synchronization is achieved without the use of common control channel Performance results indicate that proposed schemes perform better than existing approaches in terms of handoff delay and throughput.

### 4.9 Cognitive learning based spectrum handoff

In the study [18], Feng et al. introduced a cognitive learning algorithm which is used to determine the channel sensing sequence for channel selection during handoff. To model moreover a real process, each time slot comprises of three parts: spectrum sensing time, transmission time and handoff time. Sensing is done at the start of each time slot to check where it is occupied by primary user or not. The cognitive user device learns and stores the data of channel sensing on the basis of idle probability. During the handoff process, the cognitive radio will make use of this data, and senses the channel in descending order of idle probability. Simulation results demonstrate that the proposed algorithm can cut down the average handoff time as compared to random access algorithm.

### 4.10 Proactive handoff policy for spectrum handoff

Loganathan et al. [19], demonstrate that if the target channel sensing time and handshaking time are high then the proactive-decision spectrum handoff is better than reactive-decision spectrum handoff on the basis of extended data delivery time. In order to reduce the collisions with primary users, cognitive radio user switch proactively to new target channel before the appearance of primary users. Simulation results reveal that the combination of proactive sensing and predictive channel switching performs better for different arrival rate of primary users.

### 4.11 Spectrum handoff based on Hidden Markov Model

In the study [20], Pham et al. proposes a spectrum handoff model based on hidden and observation probabilities of Hidden Markov Model in order to optimize the spectrum handoff scheme and to analyze the state of channel in each time slot. Simulation results in terms of average probability of detection and average probability of mis-detect and false alarm shows improvement in the performance of system. In addition to this analysis shows that the proposed model is adaptive in nature and can be applied to spectrum mobility in cognitive radio network.

## 5. Spectrum Mobility Challenges

The following are the open research issues for efficient spectrum handoff or mobility in cognitive radio networks

- Dynamic spectrum availability

Spectrum mobility in time*:* As the spectrum availability in cognitive radio networks is time-varying in nature, cognitive radio network needs to mitigate this availability by performing adaptive mobility management based on available spectrum in time domain and according to the requirement of cognitive user. Spectrum mobility in space*:* The available bands also change as the user moves from place to place. As a result, spectrum mobility and user mobility must be jointly considered in mobility management.

- Wide range of available spectrum

The cognitive radio network requires reconfiguring the operating frequency of radio frequency front end so as to be adaptive to a new spectrum band. This is because; the available spectrum bands are not adjoining and found over different frequency ranges

- Switching delay

As and when, the best available spectrum is selected, the next issue is to design new mobility management approaches to reduce delay during the spectrum handoff process.

## 6. Conclusion

Cognitive radios provide an immense untapped potential to wireless systems. In this paper, we have provided a systematic overview on cognitive radio systems. Due to vast explosive research in this field and diversity of existing technical approaches, this paper had a difficulty in covering all the related topics. Instead, the main focus in this paper has been on spectrum mobility in cognitive radio networks which is the most crucial part in cognitive cycle. Its key features, performance metrics and challenges involved are presented in this paper. We hope that this article can help researchers and it provides a glance of technical challenges in spectrum mobility.

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